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COLD STRESS: PARAMETERS, EFFECTS, MITIGATION

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FOREWORD

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Horace F. Drury

HORACE F. DRURY
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ABSTRACT

The complex interaction of cold stress with environmental and organismic variables in exercising influence on human performance is a problem that still requires extensive investigation. Some relatively well-known interactions of cold with other stressors are reviewed. A description of the functioning of thermoregulative mechanisms in relation to cold stress and cold injury as a result of exposure in extreme climates is presented. Ways and means of counteracting cold stress to improve task performance are emphasized. The literature relating personnel selection, acclimatization, training, indoctrination, leadership, morale, and physical protection to the mitigation of cold stress and to measures of performance effectiveness is reviewed. Despite the paucity of meaningful data, it is felt that adequate and encouraging progress is being made in the understanding of the psychophysiology of cold stress.

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SECTION 1. INTRODUCTION

Earlier reviews in this series on military small group performance under isolation and stress included reference to cold stress in the broad frame of reference of adjustment at remote duty sites in the Arctic. It was concluded (a) that cold does not appear to be a serious threat to adjustment for the majority of military personnel, although fine manual dexterity is impaired by intense cold, even with special clothing and mittens (Braun and Sells, 1962), and (b) that selection of personnel for assignment to remote Alaskan duty sites does not appear feasible, although valid indications exist for consideration of negative screening procedures (Sells, 1962c).

The present review is both an extension of the coverage of the earlier papers and a more detailed study of the literature on cold stress. It considers research on the mechanisms of body temperature control under exposure to cold as well as physiological injury and dysfunction in extreme cold, effects of cold on task performance, morale, and adjustment, supportive and protective measures, individual differences in cold tolerance, and social influences. The paucity of controlled psychological studies in this area is notable. Although no claim of comprehensiveness appears justified, in view of the scattered sources of literature on these topics, available bibliographic sources were exhaustively screened.

Heat and cold are well-known sources of stress in all branches of military operations. The current military activity in the tropics, and the long-standing military operations in the severe conditions of the arctic and antarctic programs, high altitude and space flights, and long range undersea operations have greatly increased the need for knowledge in the areas of thermal stress, acclimatization, thermal injury, and protective measures.

Because of the sheer complexity of the problem of thermal stress, due to the varied influence of numerous variables producing joint effects on behavior, the quantity of experimental research in this field can be regarded as slight when compared with the questions that still remain unanswered. The area of the influence of extreme environmental conditions on human behavior is still in its infancy.

The interaction of heat and cold with humidity, air movement, clothing insulation, physical exercise and other factors in affecting the psychophysiological behavior of the human organism has been relatively well studied. Much less is known, however, on the facilitating or inhibiting effects on resistance to thermal stress of other relevant variables, such as air ions, radiation, drugs, diet, isolation, fear, darkness, motivation, personality traits, group structure, task orientation, and task load. Consequently, thermal extremes cannot be considered as an independent source of stress exerting a uniform effect on the human organism independent of other interacting organismic and environmental states. The study of thermal stress, as the study of all other known variables, is a multifaceted problem and needs to be viewed as such if adequate generalization to practical and realistic situations is to be made possible.

The appropriate conceptualization of the problem requires not only recognition and specification of the relevant variables on the stimulus side, but also careful specification of the response (criterion) variables. In experimental situations rectal temperature, shivering, vasoconstriction, and blood pressure have often been taken as indicators of thermal stress. In a military real-life situation the successful accomplishment of a task or mission under thermal stress, without irreversible damage to the human organism, would be of more direct concern than these associated physiological reactions, although the latter may be useful in understanding performance effects in terms of their demonstrable influence on the accomplishment of the task.

Thus, the question to be asked in the evaluation of performance effects of thermal stress is not what degree of shivering and vasoconstriction occurs or how far the rectal temperature drops under a specified stressful environmental circumstance, but rather the extent to which a given task or mission can be successfully accomplished in the frame of reference involving

particular categories of individuals and the observed changes in body temperature, vasoconstriction, shivering, and other reactions. Definitive answers to this last question, with reference to various environmental situations, would be of practical value in aiding the planning and execution of arctic, antarctic and tropical civilian and military operations. Yet answers of this nature are few in the literature, and those that do appear are largely based on anecdotal reports.

A word of clarification is in order at this point. In seeking molar answers to questions of extreme environmental stress, molecular investigations into bodily changes in physiological functions are not irrelevant. Indeed, molar answers to practical questions depend heavily on molecular facts. Without detailed information on specific physiological processes under stress no satisfactory, adequate, and thorough molar answer is possible. However, such information by itself is insufficient and the very exigency of understanding behavior mechanisms in complex real-life situations clearly points to the fact that research on a molar scale under the closest possible simulation of realistic environmental conditions and real-life missions and tasks is badly needed.

The review undertaken in the following pages concentrates on information accumulated through molecular laboratory research on cold stress, although it also includes observations made in real-life situations in northern climes. Yet due to the paucity of literature on the latter situation the review of it will of necessity be brief.

SECTION 2. MECHANISMS OF BODY TEMPERATURE CONTROL UNDER COLD EXPOSURE

Most of the biological functions of the human body make adjustments in order to maintain a homeostatic balance. Under light, moderate, or extreme variations in environmental temperature the thermoregulative mechanisms of the body make critical physiological adjustments to maintain a stable internal body temperature. Rectal temperature is generally accepted as being representative of internal body temperature, with a normal range from 36.2°C to 37.6°C. Variations within this range due to age, sex, emotional state, dietary status, diurnal and individual cycles, are common occurrences (Adams, 1960). In cold environments the thermoregulatory centers of the body function to maintain stability of the normal body temperature by compensating for heat losses through heat gains.

The particular methods of maintaining the normal body temperature within a species or between species depend on the availability and flexibility of heat exchange mechanisms (Adams, 1960). Under exposure to cold, human compensatory responses start to occur at temperatures below 20°C (clothed and at rest) or at 28°C (naked) (Macfarlane, 1963). As skin temperature is reduced, reflex cutaneous vasoconstriction occurs in toes, feet, hands, nose, and ears. Venous pressure rises and venous volume decreases. These physiological adjustments reduce the temperature of the skin by reducing skin blood flow. With reduction of skin temperature, the heat gradient between the skin and the environment is diminished, thus reducing heat exchange between the colder environment and the warmer body. Vasoconstriction also enhances the functional insulation of the skin by reducing convective heat losses from the blood. Adams (1960) cited work by Hardy and DuBois in support of the conclusion that conduction is not substantially reduced at temperatures below 28°C. Thus, supplementary mechanisms of adjustment are required.

At this stage the body resorts to another mechanism to maintain constant internal temperature. Blood returning from the periphery starts to flow back via deeper venous routes. These alternate routes allow cool venous blood to pass adjacent to warm arterial blood channeled toward the periphery. Returning

venous blood is thus prewarmed before entering the heart. Concurrently arterial blood is cooled, thus minimizing heat losses upon reaching the periphery (Adams, 1960).

As environmental temperature decreases, the body also resorts to mechanisms of thermogenesis. One form of heat production is gross shivering which tends to compensate for heat losses with which the adjustments cited above have not been able to cope. Then, to supplement further and aid the mechanisms of thermal balance mentioned thus far, muscle and liver metabolisms and thyroid and adrenal hormones are summoned into action. An increase in output and turnover of thyroxin and adrenal cortical hormones is observed. It is interesting to note that the response pattern of output of thyroxin and adrenal cortical hormones observed under extreme cold also occurs in other stress situations (Macfarlane, 1963).

Below rectal temperatures of 27°C-30°C the pattern of heat conservation through vasoconstriction, shivering, and increased endocrine output ceases to be effective and all central and peripheral cold mechanisms fail (Adams, 1960).

Several physiological reactions to cold in addition to the ones mentioned above have been cited by Tromp (1963, p. 243). These consist of larger urine volume, lower respiratory metabolism, decreased oxygen saturation of the blood, and higher pH of urine.*

Although environmental temperature is discussed as a single variable, the interactive or additive effects of other stressors present in the environment, in addition to cold, must not be overlooked. It is generally accepted that the presence of additonal stressors has the effect of lowering the biological and psychological stress-resistance capacity of the organism. Two important environmental factors that operate in conjunction with cold to increase the effects of cold stress are humidity and air movement.

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*A detailed account of biophysiological responses to cold and an anatomic and functional description of the thermoregulation center is given by Tromp (1963).

HUMIDITY

It is well-known that there is no substantial difference in the nonevaporative heat loss of the skin whether humidity is high or low. It is also widely accepted, from verbal reports and personal experience, that an increase in humidity almost invariably is accompanied by feelings of discomfort during either warm or cold weather. Yet, a few experiments have presented evidence contrary to this everyday "knowledge" and common expectation. In an experiment by Burton, Snyder and Leach (1955), as reported by Tromp, nine unclothed subjects were exposed lying down for 100 minutes to temperatures of 48° and 58°F with 30 per cent and 80 per cent relative humidity, respectively. Skin temperatures remained practically the same under these widely different degrees of humidity, but on exposure to cold rectal temperatures rose more when humidity was low, suggesting a greater physiological response to vasoconstriction. The incidence and intensity of shivering and the sensation of cold were greater when humidity was low, despite the fact that skin temperatures were the same. The surprising result of this investigation was that the subjects reported a greater sensation of cold with low humidity, whereas the opposite would usually be expected. Several other experimenters have obtained different results. However, Tromp (1963, p. 224) explained the discrepant reports of comfort with different levels of humidity by stating that humidity as such cannot be perceived by the human body and that only differences in humidity at a given temperature are perceived.

Despite the conflicting results of different experiments, it is generally accepted that greater discomfort is experienced during cold humid weather.

The capacity of the skin to absorb moisture, which increases thermal conductivity of the skin near the cold receptors, can be one of the various factors accounting for the increased sensation of discomfort (Tromp, 1963, p. 225). There is no evidence, however, that different thermoregulatory mechanisms are marshalled into action when the air is humid, nor that thermogenesis follows a different pattern. The same reactions that take place in dry and cold weather, probably take place in humid and cold weather. Whether the temperature threshold at which the various thermoregulatory mechanisms start their emergency

functions is lowered or heightened in cold and humid air is a point that needs clarification.

AIR MOVEMENT

It is common knowledge that air movement has a cooling effect on the body, which increases with the speed of movement. Air movement increases heat loss from the body as it disturbs the fairly constant layer of warmed air that surrounds the body in still air. Tromp (1963, p. 231) has suggested that there is an adequate rate of air movement that creates an invigorating environment and that variable rather than monotonous air movement is more bracing. His suggestions apply primarily to air movements in a room or building, but can probably be extended to breezes in temperate climes. Arctic winds, on the other hand, are uniformly detrimental to survival under extreme cold and inhibit to a great extent the accomplishment of an outdoor mission. Tromp (1963, p. 226) reported that a skin temperature of 32.5°C at an ambient temperature of 15°C drops 11.30°C at windspeeds of 282 cm/sec.

Arctic winds coupled with snow flurries do not only lower the temperature of the body, thus taxing the physiological functioning of the organism, but also make the accomplishment of an outdoor task extremely difficult, if not impossible. Snow driven into the eyes obstructs vision to a substantial degree and goggles are of no great use since they freeze up almost immediately. This situation helps to emphasize the point that physiological adaptation to cold in a cold chamber, while relevant for the controlled study of the phenomenon in molecular perspective, is only an intermediate objective in the study of psychophysiological effects of realistic cold environments on behavior.

OTHER FACTORS

In contrast to the relatively extensive information on the interaction of cold with humidity and air movement in reducing the physiological resistance of an organism to meteorological stress, comparatively little is known about the effects of air ions, polarized light, electrical fields, and several other climatological and meteorological variables on the human body. How these variables would interact with cold in modifying the physiological mechanisms of the human organism and thus influence the

performance of a task or accomplishment of a mission is hard to conjecture. Scientific progress in psychobiometeorology has been slow. Yet, several studies of recent vintage may soon provide enlightening new information on the effects of meteorological variables on behavior (Tromp, 1963; Muecher and Ungeheuer, 1961; Moos, 1964).

SECTION 3. PHYSIOLOGICAL INJURY AND DYSFUNCTION SUFFERED IN EXTREME COLD

The parts of the body most susceptible to cold-injury are the extremities, which present the largest exposed surface, for heat loss, from the underlying core. Macfarlane (1963) listed three types of cold injury.

A. Chilblains. Chilblains are a relatively mild form of tissue damage. Poor circulation, as a result of cold, results in damage to the tissue of the extremities. Local itching and swelling characterize this form of injury.

B. Wet cold syndromes. The main exemplars of these injuries are the well-known trenchfoot and immersion foot. They result from exposures below 12°C for several days. The moisture from cold and sweat contribute to the pathogenesis of these disorders. Feet and legs become cold, pale, numb and cease to sweat. After initial vasoconstriction, vasodilation takes place and the feet become red and swollen. Nerve injury is frequent. Hypalgesia and anesthesia persist for weeks after the feet have been warmed. Blood vessels are damaged and plasma and red cells leak into tissue spaces.

C. Frostbite. These injuries result from prolonged and severe vasoconstriction at temperatures below 0°C. In mild cases, tissue is not necessarily frozen. In more severe cases, ice penetrates the tissue, causing necrosis, and very often gangrene sets in if circulation has been severely reduced. On warming of the injured extremities, vasodilation and swelling occur. Considerable pain and damage to the liver, kidneys and adrenals are sometimes noted (Lewis, 1955; Macfarlane, 1963).

Environmental factors, such as winds coupled with cold, and organismic variables, such as poor circulation in the extremities, increase the danger of cold injury. Lewis (1955) classified cold injuries into categories as to their degree of severity. These are characterized by (a) loss of superficial dermal layer, (b) loss of full thickness of skin and superficial subcutaneous tissue, (c) loss of deep subcutaneous tissue and distal parts, and (d) loss

of major tissue, including bone. Results of experiments by Lewis indicated that nerve and muscle tissue were more susceptible to cold injury than skin, connective tissue , tendon and bone.

Drury (1964) reported three stages by which ice invades the tissue:

A. Superficial freezing. This occurs at high subzero temperatures. A thin blanket of ice spreads over and underneath the thin layer of tissue, advancing in all directions.

B. Intercellular freezing. In this stage, ice from the superficial layers starts spreading between the cells. In invading this intercellular space the advancing ice uses tissue elements and collagenous fibers as pathways.

C. Intracellular freezing. Ice invades the cells and blood cells freeze suddenly. Ciliary activity is irreversibly affected. Upon warming, the erythrocytes burst and blood vessels assume an irregularly beaded bulbous appearance.

The treatment of bodily injuries resultant to severe cold is a problem that has been given considerable attention. The literature indicates that severe injuries received under extreme cold are usually irreversible. This is attributable to the fact that frostbite is rarely detected by the individual at its incipience. By the time that it reaches suprathreshold levels, extensive damage to tissue and blood vessels has already taken place. The condition is often further aggravated by the concomitant effects of delay in transporting the injured person from an isolated region back to a hospital with adequate medical facilities. Gangrene and damage requiring amputation of fingers and toes are quite common.

Specific therapeutic procedures are usually of little avail when irreversible tissue damage has already taken place. Meryman (1953) reported that rapid thawing of frozen tissue may inflict further damage. Lewis and Hoak (1956) corroborated Meryman's finding that delay of rapid rewarming for 30 minutes reduces the extent of gangrene. The results of these experiments suggest that damage to tissue occurs not only when tissues freeze, but also in the thawing period as well.

Theis et al. (1951) found that the clinical use of heparin reduces the extent of gangrene and the duration of hospitalization. Douglas (1960) reported negative results for ultrasound therapy in frostbite.

Several authors have expressed the considerable doubt and disagreement as to the best method of treatment of cold injury that exists in medical circles. As Theis et al. (1951) pointed out, the prevalent objective of cold injury treatment is the prevention of further damage rather than restoration of damaged parts and functions, since in most cases of cold injury these have been irreversibly affected.

SECTION 4. DETERIORATION OF TASK PERFORMANCE UNDER COLD STRESS

Cold stress not only affects the physiological mechanisms of the body, producing such reactions as shivering and vasoconstriction; but also produces decrements in task performance. Numbness of the fingers produced by cold stress leads to deterioration particularly of performance on tasks requiring fine manual dexterity. As a consequence, duties requiring manipulation of knobs, switches, push-buttons, keys, screws, nuts and bolts become well-nigh impossible to accomplish.

Clark (1961) reported that manual performance on a knot-tying task was severely hindered when hand skin temperature fell to 55°F and continued to deteriorate rapidly as a function of duration of exposure. Clark and Cohen (1960), in an investigation to determine the effects of rate of cooling on manual performance, found that slow cooling produced a substantially larger decrement in performance on a knot-tying task than fast cooling. In addition, the effects of slow cooling persisted even after rewarming, whereas the performance decrement produced by rapid cooling disappeared after rewarming. McCleary (1953) found that as temperature was lowered, progressively greater decrements occurred in performance of a manual task.

The extremities can be rather effectively insulated by gloves and arctic mittens, but these are so bulky that they hinder the performance of tasks requiring fine manual dexterity. In this case, personal protective equipment merely exchanges one source of performance decrement for another (McCleary, 1953). Karstens (1963) indicated that when mittens and gloves have to be removed periodically in aircraft maintenance work requiring finger dexterity, the result is a substantial loss of effective working time. Blair and Gottschalk (1947) similarly found performance decrement for Signal Corps operators wearing arctic uniforms in environments of -13° to -40°F.

Torrance (unpublished manuscript) reported the effect of cold on a verbal recall task. One group of men, briefed in the open air at 8°F, were allowed to rewarm before the recall task.

The other was not. The group allowed to rewarm recalled about twice as much as the group not allowed to rewarm.

Decrement in performance in extreme environments can also be attributed to substantial energy expenditures incurred in coping with the environment. Rogers, Setliff, and Klopping (1964) reported that a solitary survivor in a subarctic environment can be expected to expend from 5000 to 6000 Kcal during the first 24 hours in which he undertakes survival procedures. This caloric cost is independent of environmental temperatures as low as -30°C. The drastic caloric deficit incurred through energy expenditures of this nature cannot be met without disastrous exhaustion unless the individual is "thoroughly fit." Performance decrement, malaise, and discomfort in such a taxing situation can be attributed to the caloric loss as well as to "isotonic dehydration and its consequent hypovolemia and hemoconcentration."

Measures for counteracting performance decrement and deterioration in cold environments are many, although none of them is completely satisfactory. Factors instrumental in increasing tolerance of cold stress are reviewed later in this report.

SECTION 5. DETERIORATION OF MORALE AND AFFECTIVE DISORDERS UNDER COLD STRESS

Isolated cases of cold neurosis have been cited in the literature of cold stress (Macfarlane, 1963). Incidents of deterioration of morale, anxiety, increased irritability, depression, sleep loss, and personal untidiness in extremely cold environments (military and scientific arctic missions) have also been reported (Reidy, 1960). Despite the common belief, it is significant that informed scientific opinion is skeptical concerning any direct relation of these behavioral manifestations to the effects of the cold environment. In most cases individuals exhibiting the symptoms reported were well-protected from the cold. The uncontrolled effects of fear, remoteness, isolation, confinement, interpersonal friction, and lack of effective leadership have been judged to have contributed more to deterioration of personal habits, behavior, and morale than the cold environment *per se*. In most cases the individuals exhibiting deteriorating tendencies could be said to have adjusted poorly to their respective situations and would probably have exhibited the same symptoms under other stresses in those situations. Such difficulties may involve the physiological mechanisms of thermal adjustment, but it is generally recognized that poor psychological adaptation is not necessarily indicative of poor physiological adaptation to the cold.

SECTION 6. SUPPORTIVE AND PROTECTIVE MEASURES IN RELATION TO COLD STRESS

Several means of protecting the human organism and enhancing task performance in cold environments have been studied intensively. These range from physiological acclimatization, through clothing and diet, to selection of "fit" individuals, and group dynamics. The following sections review some measures that have been found useful in preparing the human organism for cold stress as well as means and devices that have a salubrious and positive effect on task performance and mission accomplishment.

ACCLIMATIZATION

As mentioned earlier, the maintenance of high body temperatures while functioning in low ambient temperatures is crucial to survival and comfort in cold environments. The adjustment of physiological functions to cold environments, with resulting increased capacity to withstand low temperatures, is known as acclimatization. The process of acclimatization utilizes fine and complex mechanisms, the cellular basis of which is not yet well understood (Macfarlane, 1963). Acclimatization is usually achieved within one week, but two or three weeks are generally necessary to reach a steady state. At the outset of acclimatization, the physiological compensatory responses reviewed in the preceding pages are manifest. Shivering, peripheral vasoconstriction, increased venous pressure, diuresis, accelerated thyroid and adrenal cortical hormone production, "hunting" oscillation of finger blood flow (See discussion below of tests for thermoregulative efficiency), and increased oxygen consumption depict the pattern of physiological reaction to cold stress.

In the unacclimatized individual, despite these responses to maintain body heat, conservation of normal body temperature is not as effective as in the fully acclimatized individual. The acclimatized organism wastes considerably less heat than the unacclimatized (Macfarlane, 1963). Acclimatization is indicated as cardiovascular, endocrine and renal emergency activation become less and less manifest. The initial increased output of

adrenal and thyroid hormones, elevated blood pressure and diuresis, shivering, increased oxygen consumption, and vasoconstriction start diminishing. Macfarlane pointed out that this pattern of sudden increase and gradual decrease in emergency reactions, specifically endocrine output, is the same as that which the organism manifests in response to a variety of stressors. As the initial overswing upon exposure to cold stress gradually subsides the individual is said to be acclimatized.

Davis (1961a, 1961b, 1961c, 1962), in a series of meticulous and painstaking studies, investigated the process and effects of acclimatization. He demonstrated that acclimatization was more efficient, faster, and retained longer when subjects were exposed to low temperatures, unclothed and unprotected, in cold chambers. Because this method involved scheduled exposure and utilized cold chambers, rather than "natural" exposure in the daily course of living in cold climate, Davis referred to it as "artificial" acclimatization. While natural acclimatization to cold was found to be lost in the summer months, artificial acclimatization was retained through the summer into the next winter. Studies at Fort Knox and in Alaska showed that individuals, appropriately clothed for their daily living, failed to acclimatize fully, although they did so to the same extent, irrespective of the range of daily environmental temperatures. Thus, just living in a cold environment (Alaska) was not sufficient to induce full acclimatization when it occured under natural conditions. It seems, therefore, that artificial acclimatization to cold has definite advantages over natural acclimatization.

Several indices of acclimatization have been used separately or together by different investigators. These have ranged from skin and rectal temperature, peripheral circulation, and shivering, to subjective feelings of comfort. Oxygen conservation, heat production, and changes in enzyme and endocrine systems have also been utilized as indices of acclimatization. Davis (1961a) found the most desirable index of acclimatization to be shivering, which decreased significantly in subjects artificially acclimatized in cold chambers. Rectal temperature showed a significant decrement as a result of acclimatization in one study, yet in other investigations by Davis this index failed to show consistent changes.

Davis reported no meaningful changes in skin temperature of any area of the body as a result of acclimatization procedures. Milan et al. (1961), on the other hand, investigating in the physiological responses of naturally acclimatized individuals in the antarctic, observed an increase in skin and foot temperatures over the year, but found no difference in rectal and finger temperatures. Manifest decrease in shivering from fall to winter and spring was evident.

Seasonal variation in acclimatization to cold is an important variable to be considered in both natural and artificial cold acclimatization. In naturally acclimatized subjects seasonal cold acclimatization, as indicated by Davis, reaches its maximum around March and is at its minimum in September. Davis (1961a) found a significant decrease in heat production in nude subjects exposed to cold in the summer, but no change in heat production in subjects artificially acclimatized in the winter. These findings indicate that the winter group started its artificial acclimatization with a lower level of heat production than did the summer group. In both groups, however, heat production remained above basal level throughout the duration of the experiments. The decrease and eventual cessation of shivering, and the high heat production despite the cessation of shivering are interpreted by Davis as evidence for mechanisms of nonshivering heat production.

Studies of cold endurance and task performance of acclimatized subjects have been given less attention than they deserve. Eagan (1962), measuring resistance to finger cooling, observed that mountaineers, who had undergone extensive cold exposure, and Eskimos were able to withstand the exposure better than control subjects. Some of the mountaineers who had not suffered cold injury maintained more economical finger temperatures than the Eskimos. Miller and Irving (1962) reported that Eskimos have higher minimal and terminal finger temperatures than whites; in addition, "unaccustomed" white men experienced marked discomfort to hand cooling as compared with Eskimos and whites accustomed to cold. Nelms and Soper (1962) found higher finger temperatures both during vasoconstriction and vasodilation in experienced fish filleters than in controls, when their hands were immersed in cold water. Some control subjects fainted, others experienced considerable pain, whereas the filleters were unaffected. Tromp (1963, p. 241) reported an experiment by

Glaser and Whittow (1957) in which the pain and rise in blood pressure induced by hand immersion in icy water diminished and were eventually lost after repeated immersions. It appears that people exposed to strong fluctuations in temperature develop an efficient skin temperature control mechanism and adapt readily to cold. Davis (1961a) observed that subjects acclimatized in the cold chamber were able to fall asleep under testing conditions.

All these studies indicate that cold tolerance at the extremities is increased by acclimatization. It is reasonable to state that acclimatized individuals will not experience as much distress under cold as unacclimatized persons and will be able to perform tasks more satisfactorily.

The occurrence of cross-adaptation, including increased tolerance of cold as a result of acclimatization to heat and vice versa, has been mentioned by Trumbull (1964). The basis for and existence of such a mechanism have been brought into question, however, by the work of Davis (1961a), Macfarlane (1963), and others. According to these investigators there seems to be no evidence that heat exposure affects cold acclimatization either favorably or adversely, or that cold exposure increases tolerance to heat stress. In a related study, Barnett (1961) reported that body heating prior to cold exposure is ineffective in extending tolerance to extreme cold.

Tromp (1963, p. 231) indicated that temperatures found uncomfortably warm in the winter are bearable in the summer because of acclimatization to higher temperature in the summer. Conversely, temperatures experienced as cold in the summer are found tolerable in the winter. If anything, such phenomena suggest the opposite of cross-adaptation. The diminution and loss of cold acclimatization over the summer appear to be related, not to the presence of heat, but rather to the absence of cold (Davis, 1961a).

On the basis of all the evidence available it thus appears most likely that the physiological processes of heat and cold acclimatization are independent, that they do not influence one another; yet that they can coexist within the same organism. These physiological processes are also independent of, but interact with psychological processes of accustomization, habituation, and adjustment to places, climates, diets, tasks, social situations,

surrounds, and routines. Davis (1961a) emphasized that although manifest physiological changes occur in acclimatization, it would be presumptuous to overlook the roles of psychological habituation and accustomization in the general process of acclimatization.

To recapitulate the practical and applied aspects, artificial acclimatization appears to be an effective way of increasing the cold tolerance of individuals and of helping them to perform more effectively under cold stress.

DIET

Cold stress and acclimatization have been shown to affect, among other things, the endocrine system, enzymes, and metabolism of the body. Torrance (unpublished manuscript) reported a greater tendency to eat fats in colder climates and found that pemmican was more acceptable as a comestible in severe weather conditions. Milan and Rodahl (1961) reported an increased avidity for fat in personnel at an antarctic base.

Rodahl, Horvath et al. (1961) studied the effects of four different diets on physical performance capacity at temperatures of 22°C and 8°C. At an ambient temperature of 22°C no significant differences were found among the four diets. At ambient temperatures of 8°C marked deterioration on the treadmill test occurred in subjects living on a diet deficient in calories and proteins. Tromp (1963, p. 242) reported that Vitamin C increases resistance to cold stress and facilitates adaptation by increasing the activity of the adrenal glands.

Kreider (1961) found that composition of diet had no effect on rectal, skin, and toe temperatures at ambient temperatures of 30°F. Milan and Rodahl (1961) observed that the percentage of calories, proteins, and fat furnished to antarctic personnel in Little America was not different from that of U.S. troops stationed elsewhere. These investigators attributed part of the avidity exhibited by antarctic personnel to the function that eating might serve in alleviating the tedium of long isolation. The increased caloric intake observed in cold and isolated climes might be a resultant of both physiological and psychological needs.

Rogers, Setliff, and Klopping (1964), in investigating the calorie cost in simulated subarctic survival situations, found the calorie expenditure to be principally determined by the physical task undertaken rather than by the environmental temperature, when the temperature was above -30°C.

In general, this review of the literature indicates that the evidence concerning the value of special diets as a means of increasing cold tolerance is at best equivocal. The importance of proper calorie and water intake, however, cannot be gainsaid even if the use of diets of special composition is of doubtful value.

CLOTHING AND SHELTER

Insulation is a very important measure in counteracting cold stress. Where adequately heated buildings can be constructed, protection can be satisfactorily achieved and cold stress presents no immediate problem to individuals working and living indoors. Denley (1957) found that even a pneumatic shelter raft can be a satisfactory shelter for emergencies and for short temporary missions in the Arctic. The problems associated with confined living arrangements, however, are major, although largely psychological. As stated before boredom, isolation, and confinement increase the irritability of personnel. Deterioration of morale is noticed. Means of alleviating these tensions are discussed below.

The standard clothing designed for arctic personnel has been well investigated. The types of cloth favored for protective arctic garments are those that have the property of maintaining still air in the interstices and that prevent air from moving within or passing through (Renbourn, 1963). Mayer (1960) found that insulated underwear of 100 per cent nylon with polyester provided the person with adequate comfort in temperatures of -35°F without wearing an arctic parka. The nylon underwear was worn with waffle-weave underwear, MA-1 jacket with hood, pile cap, two pairs of ski socks, one pair of cushion sole socks, CWU/1p coveralls, and mittens. Skrettingland et al. (1961) evaluated the boots worn with cold environments and found the chippewa boot adequate for ambient temperatures of -12°C. Veghte (1964) found the parka hood adequate without face mask in temperatures

of -62°C for 40 to 50 minutes. The coldest skin temperature was 7°C, and no pain was experienced by the subjects.

Despite the adequacy of arctic clothing, the maintenance of temperature in the extremities above critical levels is still a problem. Martorano (1961), in evaluating divers' suits for maintenance of body temperature, observed that the rate and degree of cooling of the extremities were directly related to the thickness of insulation over these areas. Unfortunately, as mentioned above, Skrettingland (1961) and others have reported that tasks requiring finger dexterity are impossible to accomplish with the hands encased in arctic mittens and no satisfactory solution has been found to the problem of performing a fine manual dexterity task in extreme cold while keeping the hands warm at the same time. As Veghte (1961) has shown, adequate insulation of the body does not ameliorate cold tolerance in the extremities. Veghte's work did demonstrate, however, that with the extremities protected, the rest of the body, with the exception of the ears, could tolerate temperature as low as -18°C for 83 minutes when thermistor underwear was worn.

The maintenance of adequate skin temperature at the extremities is thus a problem that requires further investigation. Karstens (1963) remarked that vasoconstriction and loss of dexterity occur regardless of the amount of mittens and gloves worn. For aircraft maintenance crews working in cold environments, Karstens found periodic rewarming of the extremities and the body in a shelter to be a tolerable, if not satisfactory, remedy. Mobile shelters placed over parts of aircraft have also been found to provide reasonably adequate support in protecting maintenance crews from the cold.

In conclusion, it can be remarked that when the task is not hazardous and demanding and the individual is well insulated, the limiting factor in cold tolerance appears to be the temperature of the extremities. If a satisfactory means of protecting them could be found, performance at extremely low temperatures could be greatly extended.

SECTION 7. INDIVIDUAL DIFFERENCES AND TOLERANCE OF COLD

Individuals differ in the extent to which they experience comfort and distress in the same environmental circumstances. In the same ambient temperature, some complain of warmth, while others fret about cold. Some of these differences in experience can be accounted for by adaptation, acclimatization, and habituation. However, a substantial portion of this variance might eventually be accounted for by efficiency and plasticity in physiological mechanisms of adaptation, physical fitness, personality and motivational differences, and other physical and social stimuli in the environment alleviating or aggravating individual feelings and complaints about cold.

DIFFERENCES IN PHYSIOLOGICAL THERMOREGULATION

Considerable differences have been found in thermoregulation in relation to age (Tromp, 1963, p. 229). In infants thermoregulatory mechanisms are not fully developed and body temperature is closely related to fluctuations in ambient environmental temperature. Thermoregulatory control is attained within two years (Adams, 1960). Buchanan and Hill (1947), as reported by Adams, found a positive relationship between ability to regulate body temperature and the development of myelinization in the hypothalamus. In the old, likewise, thermoregulation becomes poorer. Their circulation is feeble and their adaptive capacity to change in ambient temperature becomes inadequate (Tromp, 1963, p. 229). Most normal adults have efficient thermoregulatory mechanisms and until now selection of arctic and antarctic personnel by testing for thermoregulatory efficiency has not been deemed important.

Tromp (1963, pp. 252-255) listed the following tests of thermoregulation efficiency of the human body:

a. Hunting reaction of Lewis. Normally, the temperature of a finger immersed in ice water drops to 0°C at first. A few minutes later, however, the temperature of the finger starts periodic fluctuation between 0°C and 5-6°C. Deviation from this pattern of rises and falls can be

accepted as an index of a less than normally effective thermoregulatory mechanism. It is most important to determine the normal pattern of the Hunting reaction for all age groups in different climatological areas to set up norms for this test.

b. Bedford's air-cooling test. The rise and fall of the temperature of the forehead are measured when an electric fan is activated. Deviations from the normal pattern are observed.

c. Water-bath test. The subject reclines in a chamber with an ambient temperature of 20°C and a relative humidity of 50 per cent. The skin temperature of the body is recorded at several places, such as forehead, cheek, and finger. Upon stabilization of the skin temperature a reflex vasodilation of the arterioles is induced by immersing the feet in a warm bath of 45°C. The time between immersing the feet and the first change in finger temperature, as well as the rate at which the finger temperature increases and the final temperature is reached is recorded. After the feet have been taken out of the bath similar observations are made. Tromp recommends that the same procedure should be followed with water at 10°C, 5°C, and 0°C.

d. Blood pressure test. Upon immersion of the hand in cold water the rise of blood pressure is recorded by means of a sphygmotonograph. The rate of increase in pressure and the pattern of the recovery curve are different for individuals with poor thermoregulative mechanisms.

e. Blood flow test. Five cubic centimeters of the third finger of the right hand are enclosed in the cup of a plethysmograph and the changes in the pattern of blood flow after immersion in water are studied. Persons having poor temperature control mechanisms are expected to deviate from normals.

f. Habituation test. When the tests cited above are repeated daily the reaction to cold diminishes gradually and may even disappear. Even after an interval of a few days little or no response is observed. Upon renewing

the test, persons with a poor ability to adapt and acclimatize to cold show a different pattern of habituation.

g. Diuresis test. In people with normal thermoregulative mechanisms a sudden drop in environmental temperature is usually accompanied by diuresis, an increase in 17-ketosteroid secretion and pH, and a decrease in chlorine secretion. According to Tromp, a deviation in the diuresis curve is indicative of a disturbed thermoregulative process. Several other aspects of the situation should be well investigated and controlled when using the diuresis test. The fluid intake of the person should be recorded prior to the test. This observation should start four weeks before the test. As diuresis is affected by the adrenal cortex, it is desirable to take an adrenocortical efficiency test.

Despite the variety of methods to test thermoregulative efficiency, none of these has been standardized and population norms have not been obtained. In addition, frequently observed deviations from the normal have not been adequately described. The need for extensive investigation in this area is manifest.

In an attempt to predict performance under cold stress from physiological measures of skin temperature McCleary (1953) divided subjects into two groups on the basis of digital skin temperature under ambient temperatures of 0°, -10°, -20°, and $-40^{\circ}F$ in a cold chamber. The high skin temperature group completed the assigned manual dexterity task more rapidly than the low skin temperature group. This result led McCleary to suggest that skin temperature might be a proper predictor of performance in the cold. A "sensitivity index" derived by calculating the ratio of the digital skin temperature when the subject reported "cold" to the time that it took to reach this temperature after the onset of exposure was found to be a fairly satisfactory discriminator of time taken to complete the dexterity task in the cold chamber. The replication of this study with a larger sample, in different climatic zones, with several predictors (e.g. shivering, skin temperature in various parts of the body) and additional performance criteria (e.g. manual dexterity task, verbal learning and recall, problem solving, reaction time) would be a worthwhile undertaking.

PHYSICAL FITNESS

Data on the ability of the "physically fit" man to withstand cold better than the unfit individual are meager despite the general acceptance of the concept. One of the apparent problems in this area is the definition and quantification of measures of physical fitness.

The available literature indicates that a physically fit person performing well in temperate climes will not necessarily perform as well in arctic and subarctic weather. The point of view suggested is that the particular kind of physical fitness required to combat cold stress is that which is acquired through acclimatization, conditioning and training. A person in good health is not necessarily physically fit to withstand the rigors of arctic weather unless he is adapted to it. Eagan (1962) found no correlation between measures of physical fitness and resistance to finger cooling.

A robust and "physically fit" person might show poorer or better resistance to cold stress depending on such factors as morale, exposure, isolation, fear, and task load. The interaction of numerous parameters in determining stress tolerance is an everpresent problem.

MORPHOLOGY

Davis (1961a) reported more than average shivering in two subjects who could be classified as ectomorphs. Fine and Gaydos (1959) found that heavy, big men felt warmer during cold stress than lightweight small men. Small men, however, showed faster recovery rates than big heavy men. The authors indicated that small men suffer less cumulative effects of cold stress than big, heavy men. The paucity of information in this field leaves the question of selection of arctic personnel on the basis of body build open. As usual, a large number of other factors needs to be taken into consideration.

DIFFERENCES IN COMPLEXION

McCleary (1953) found a consistent, yet nonsignificant difference between "blonds" and "brunets" in manual performance under cold conditions. The blond group, which included

red and brown-haired individuals as well, took less time to complete a manual dexterity task than did the brunets, who in this case were only black-haired individuals. This trend was not related to racial or national subgroups and was apparently unrelated to the "sensitivity index" discussed above. The results of this isolated report need further verification.

SEX DIFFERENCES

Women usually report greater discomfort due to cold and are said to prefer higher temperatures than men. This anecdotal observation has sometimes been interpreted as a sex difference in physiological thermoregulative mechanisms. An experiment by Yaglou and Messer (1941), reported by Tromp (1963, p. 231), however, has shown the differences in temperature sensation and comfort to be almost entirely due to differences in clothing worn.

PERSONALITY DIFFERENCES

Personality correlates of cold tolerance have been studied by a few investigators with generally negative results. Fine and Gaydos (1959) obtained rectal temperatures, morphological measurements, MMPI scores, and ratings of subjective feeling from subjects exposed nude to 78°F, 70°F, and 50°F. Subjects whose scores on the derived anxiety index deviated widely from the group norm took longer to show a rise in rectal temperature following exposure to cold. No differences in rectal temperature between the norm group and deviates were found prior to or during exposure.

Willemin, Kaplan, Katz, and deJung (1958) obtained scores on several psychological tests, biographical data, and peer ratings on 825 enlisted men in Cold Bay maneuvers at Fort Richardson, Alaska. The predictive validity of the instruments used was not at all impressive. The 1958 Combat Composites, Aptitude Areas, IN (Infantry) and AE (Combat Arms Other than Infantry) correlated .21 and .20, respectively, with peer ratings obtained on the basis of "desirability for inclusion with the rater on another cold weather maneuver." The Classification Inventory (CI), a composite measure of self-confidence, emotional stability, leadership, masculinity and social responsibility, correlated .22 with the criterion obtained from peer ratings of desirability. The Arctic BIB (Biographical Information

Blank), a self-description blank to obtain the individual's self-estimate of his ability to cope with the tasks and hardships of arctic duty, the Shop Mechanics and the Automotive Information Tests of the Army Classification Battery showed significant, but low correlations with the peer rating criterion. A low positive relationship between enlisted grade and desirability as "arctic duty companion" was also found. A multiple correlation was not reported. The question as to how representative companion desirability peer ratings are of actual performance under cold stress is highly debatable. In addition, the probability of contamination of the criterion by such factors as likability, friendliness, and the like should be deemed considerable.

Debons (1950) studied the interrelationship of MMPI scores and expressed levels of adjustment to arctic duty for a sample of infantrymen. The group that rated itself less able to adjust to the Alaskan tour had MMPI scores most like the Army AWOL soldier, indicating greater depression, more neuroticism, and more schizoid tendencies than the rest of the sample. The group of individuals that expressed itself as adjusting favorably had MMPI scores that were less neurotic than the maladjusted group; they were also significantly higher on the psychopathic-deviate dimension than the norm group on which the MMPI scale was based.

On the basis of the research reviewed, it appears that adjustment to and tolerance of cold have not been found to be significant functions of stable personality traits. Individuals who manifest considerable maladjustment, depression, loss of sleep, and other affective disturbances appear to do so for the same reasons in the Arctic as in more temperate climes. There is little evidence that this maladjustment should be attributed to predispositions reflecting particular personality or characterological sensitivities to low ambient temperatures. The combined rigors of thermal adjustment, isolation, confinement, and related factors at Arctic remote sites, with resulting frustration, boredom, interpersonal difficulties, and deprivations are sufficient to intensify and precipitate symptoms of maladjustment in some individuals, who might be screened prior to assignment if such screening were considered administratively indicated (Sells, 1962b).

SUMMARY

Although the question of selection of military personnel for arctic duty has in general been answered in the negative, the present review suggests that there is the possibility of exploiting individual differences in thermoregulation efficiency (Tromp, 1963, p. 252-255) and "sensitivity" (McCleary, 1953) that might afford a means of selection of personnel for particular tasks in which cold tolerance is critical and means of insulation and protection are not adequate, for example, the maintenance of power and communications lines and equipment in the open.

SECTION 8. SOCIAL FACTORS

Although we are not aware of any "hard" experimental data on the role of individual motivation and of group and social factors in relation to tolerance of cold stress, both anecdotal and field observations strongly support the following conclusions: (a) that the greater the motivation to achieve a particular goal, the greater the individual's tolerance of frustration and stress in activities leading to that goal (Sells, 1951; Bitterman and Holtzman, 1952; Lazarus, Deese, and Osler, 1952; Korchin, 1962); (b) that support contributing to the mitigation of stress is received in the participation in close-knit, well-trained groups through the effects of leadership, team spirit, and other aspects of the group process, and (c) that other social factors, involving intra- and inter-group relations, such as the effects of success and failure on communications, content of communications, and the like, have a significant effect on individual stress tolerance.

Karstens (1963) concluded that motivation is an important factor in the performance of aircraft maintenance crews working under adverse weather conditions. Motivated individuals were observed to make a special effort to combat the hardships imposed by the cold and to accomplish the task successfully. Reidy (1960) suggested that choosing volunteers for a hazardous and stress-laden arctic mission is an excellent selective device and a motivating force for a man to perform well.

The contributions of group processes to mitigation of the combined stresses of arctic duty have been discussed at some length by Sells (1961, 1962a, b, c). Some additional observations are included below fr[illegible]rences omitted from or subsequent to Sells' reviews.

Reidy (1960) in his observations of several groups stationed on an isolated ice island in the Arctic at different times gave a vivid description of the deleterious effects of poor leadership on morale and the friction created by poorly adjusted individuals in such small isolated groups. In the military situation, particularly, where the authority of the commander is of overriding importance in group behavior, such maladjustment may often be an effect of leadership failure, with disruptive effects

on group morale and consequently on group performance (Reidy, 1960; McCullum, 1950; Torrance, unpublished manuscript).

Bovard (1959) suggested that the presence of others, particularly those with whom the individual has previously interacted, may have "a protective effect under stress." Bovard hypothesized that the presence of a social stimulus will have a tempering effect on the individual's adverse physiological reaction to stress. Whether cold stress can be better withstood, and a high body temperature maintained in a group of persons with a previous history of interaction, than by an isolated individual is open to empirical investigation.

Separation of married men from their families, lack of sexual contact with the opposite sex, and absence of adequate recreational facilities are a few other problems that have been mentioned as affecting morale and performance adversely (McCullum, 1950; Torrance, unpublished manuscript).

The manner and thoroughness of preparatory indoctrination of personnel prior to exposure to stress is also an important aspect of stress-tolerance. Lack of competence and unrealistic anticipations resulting from inadequate or inaccurate information about expected conditions and conceivable emergencies (such as frostbite) can seriously handicap an individual or a group in environments fraught with difficulties and hazards. Proper concern for and care of injuries, alleviation of unfounded fears and anxieties, and instruction in survival procedures in the event of extreme emergencies are necessary aspects of the indoctrination and training required for personnel who are to be exposed to extreme conditions. Prior experience in similar situations is invaluable, especially in the case of leaders, such as officers and non-commissioned officers. Understanding of behavioral reactions to be reasonably expected under extreme environmental conditions and their possible effects on group morale might provide commanders and subordinate leaders helpful "insight" into these problems when and if they occur. Such "insight," "understanding," or expectation might also reduce adverse and unadaptive reactions in trying and exacting social and environmental circumstances.

SECTION 9. CONCLUDING COMMENT

This review has described the psychophysiological effects of cold stress, the diverse parameters of cold stress that have an interactive effect in lowering the individual's tolerance to stress, and the means of counteracting the compounded effect of cold stress through acclimatization, training, selection, and indoctrination. Although the multidimensional and interactive aspects of so called cold stress have often been reiterated, the requirements of literary exposition have made it necessary to treat both the effects and parameters of cold stress individually. In view of the complexity of the natural environment in which cold stress is most often encountered, it might have been more appropriate to entitle this paper, "The Psychophysiological Effects of Arctic and Polar Environments."

Despite the certainty that years of extensive experimentation and observation are yet needed to bring the scientific understanding of cold stress from its infancy to a more advanced level, comfort can be taken in the fact that investigations conducted to this date do not form a mixture of contradictions, as is so often the case in other fields of psychology and physiology. The evidence and conclusions on the effects of cold stress and the utility of counteracting measures are on the whole consistent. The investigations reported, conducted by scientists of different disciplines, are most often congruent and complementary. In spite of its insufficiency, a useful body of knowledge has started to develop in this field. Utilization of the principles and counteractive measures expounded in this paper can be expected to provide improved ability to cope with many practical situations in which cold stress and its correlates are operative.

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13. ABSTRACT The complex interaction of cold stress with environmental and organismic variables in exercising influence on human performance is a problem that still requires extensive investigation. Some relatively well-known interactions of cold with other stressors are reviewed. A description of the functioning of thermoregulative mechanisms in relation to cold stress and cold injury as a result of exposure in extreme climates is presented. Ways and means of counteracting cold stress to improve task performance are emphasized. The literature relating personnel selection, acclimatization, training, indoctrination, leadership, morale, and physical protection to the mitigation of cold stress and to measures of performance effectiveness is reviewed. Despite the paucity of meaningful data, it is felt that adequate and encouraging progress is being made in the understanding of the psycho-physiology of cold stress.

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